

SRT: The Impact of Large Antennas on Radio Astronomy and Space Science



Cagliari, Sardinia, Italy

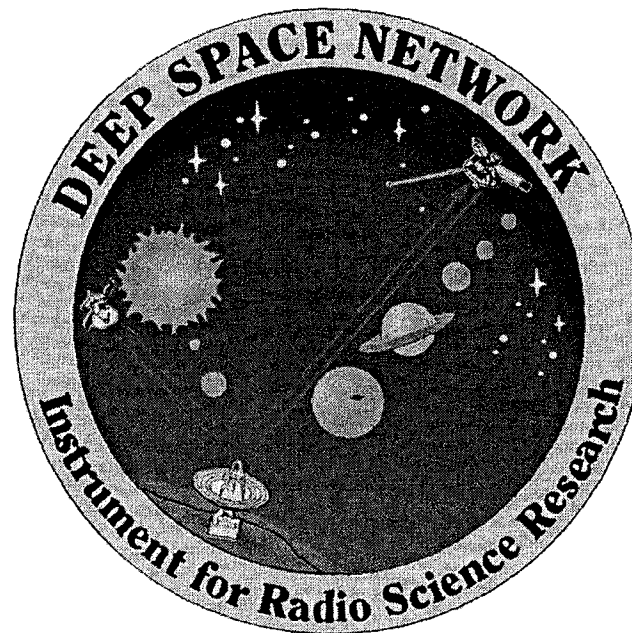
7-10 November 2001

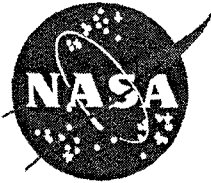
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Instrumentation of Large Radio Telescopes for Radio Science Investigations

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Abstract

Large antennas of the Deep Space Network as well as other radio telescopes have been successfully used as instruments for Radio Science research on almost every deep space mission, leading to numerous important discoveries published in scientific journals.

Radio scientists utilize the telecommunication links between spacecraft and Earth to examine very small changes in the phase/frequency, amplitude, and/or polarization of radio signals to investigate planetary atmospheric and ionospheric composition, structure of planetary rings, planetary surface characteristics, magnetic fields of the Sun and planets, the corona and solar wind, cometary mass flux and particle distribution, planetary gravitational fields, shapes, masses, and bulk characteristics, planetary range-fixes and ephemerides, gravitational waves, gravitational redshift, relativistic time-delay, wind profiles, and other phenomena.

These investigations are typically divided into two classes: propagation and celestial mechanics (gravitation). The former typically requires ultra stable one-way transmission and open-loop reception and the latter typically requires stable coherent two-way communication. The limits of sensitivity for these experiments are governed by: frequency stability, amplitude stability, signal-to-noise ratio, navigation accuracy, and the ability to calibrate the intervening media.

Required instrumentation includes open-loop receivers for phase stability, signal dynamics, multi-path, arraying, and creative post-processing; tracking receivers to provide Doppler and range data; frequency and timing systems that may include hydrogen masers, super-conducting cavity maser oscillators, or trapped ion devices; a media calibration system, and mechanical systems for blind antenna pointing.

This paper presents an overview of the DSN instrumentation as well as examples of data showing the achieved accuracies. It discusses recent technology advances and plans for future developments. A section of the paper will also summarize the important scientific discoveries from the field of Radio Science using the Deep Space Network.



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Science Overview

Scientists utilize the telecommunication links between spacecraft and Earth to examine very small changes in the phase/frequency, amplitude, and/or polarization of radio signals to investigate:

Planetary atmospheric & ionospheric composition & temp-pressure profiles

Structure of planetary rings

Planetary surface characteristics

Magnetic fields of the Sun and planets

The corona and solar wind

Cometary mass flux and particle distribution

Planetary gravitational fields, shapes, masses, and bulk characteristics

Planetary range-fixes and ephemerides

Gravitational waves

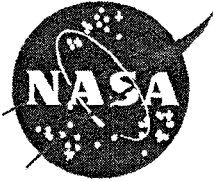
Gravitational redshift

Relativistic time-delay

Wind profiles

Radio Science publications in peer-reviewed English language journals by end of 2000:

48 in <i>Science</i>	17 in <i>Nature</i>	12 in <i>Astronomy & Astrophysics</i>
55 in <i>Icarus</i>	15 in <i>Books</i>	70 in <i>Journal of Geophysical Research</i>
12 in the <i>Astronomical Journal</i>	9 in <i>Radio Science</i>	25 in the <i>Astrophysical Journal</i>
6 in <i>Planetary and Space Science</i>	75 in other	9 in <i>Space Science Reviews</i>



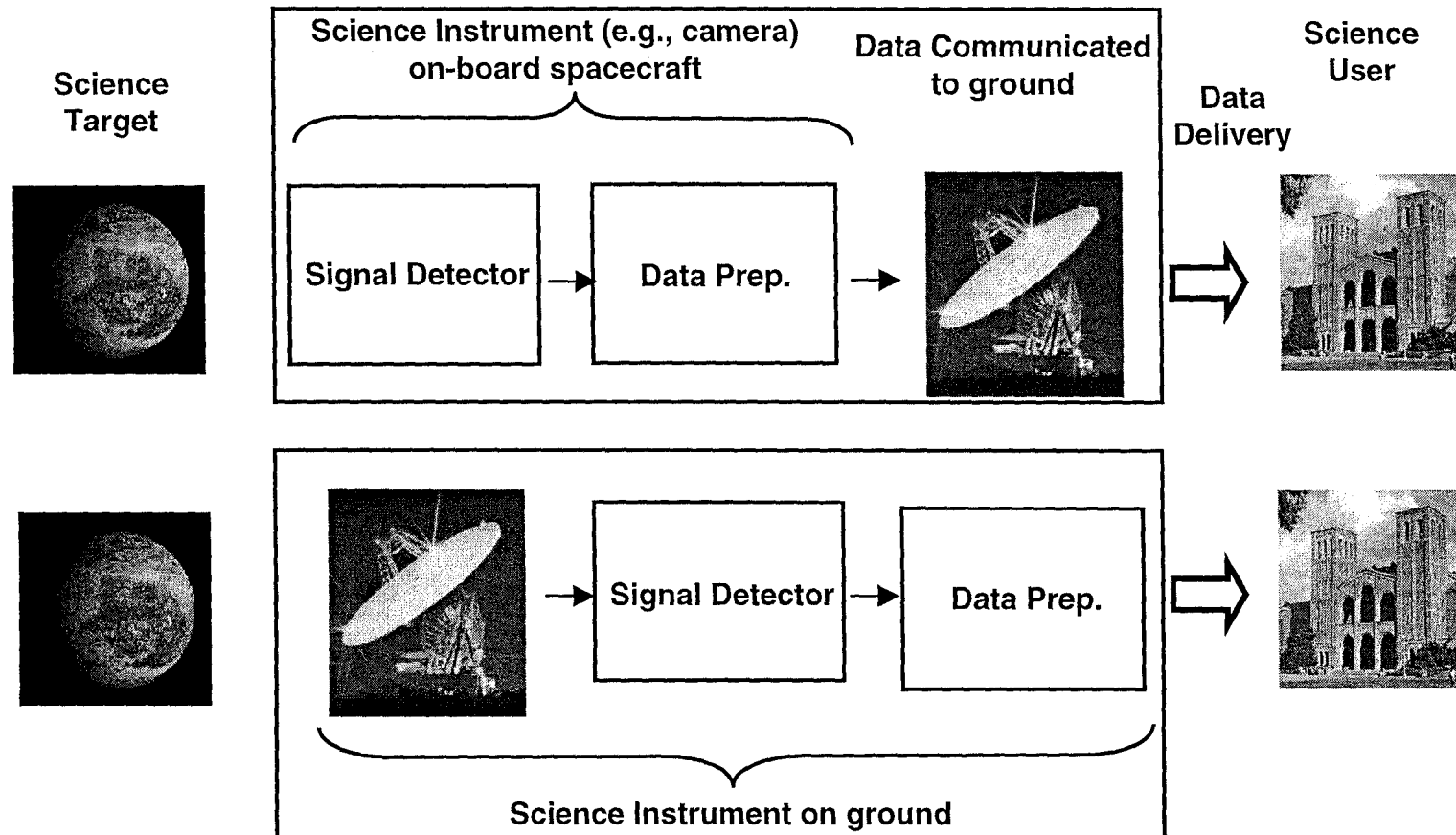
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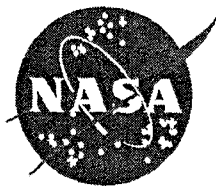
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Primary DSN function is communication and data delivery - optimize links, e.g., G/T.

DSN is also an instrument for science research - optimize performance, e.g., phase stability.



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Radio Science Discoveries Support NASA Themes

(Selected Examples)

Exploration of the Solar System

First estimate of Martian surface pressure at 12.6-cm wavelength (Mariner 4)

First measurements of wind patterns confirming features of Global Circulation Models (MGS)

First observation of Rings of Saturn and Uranus (Voyager)

Measurement of drag deceleration in the comae of comets Halley and Grigg-Skjellerup (Giotto)

Measurement of electron column density latitude profile of the Io Plasma Torus (Ulysses)

Discovery of lunar "mascons"

Masses & gross compositions of Jupiter, Saturn, Uranus, Neptune, Titan, and Triton (Voyager)

Determination of mass distribution in the interiors of the large moons of Jupiter (Galileo)

Highest gravitational field of the Moon, Mars, Venus (LPM, MGS, Magellan)

Structure and Evolution of the Universe

Lowest noise Doppler observations to date in the ~0.001-0.05 Hz band

Most accurate determination of Post-Newtonian gamma, a measures curvature of space per unit mass

The Sun and Earth Connection

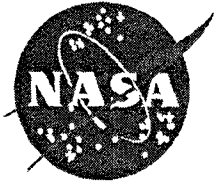
First evidence for the acceleration of coronal mass ejections far from the Sun

First evidence for the radial expansion of polar coronal holes

First detection of plumes at low latitudes and far from the Sun

First evidence for the imprint of the Sun on the solar wind

First evidence that streamer stalks are the sources of the slow solar wind



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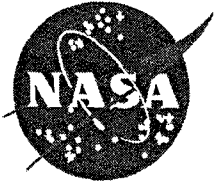
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Other Benefits from Radio Science System

- Search for lost/stressed spacecraft
- Planetary landing or orbit insertion communication
- Spacecraft nutation characterization
- Spacecraft antenna characterization
- Characterize Ka-links for future telemetry applications
- Ultra Stable Oscillator as telemetry reference
- Telemetry performance near solar conjunctions
- Radio interference studies
- Small signal from lot of noise
- Pushing limits of technology



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“Large Antennas” The World is Familiar with

The Deep Space Network is a world-class instrument for Radio Science research

Three complexes around the globe with 70-m and 34-m diameter dishes

Deep space links at S, X, and Ka-bands

70-m stations can receive right and left hand circular polarizations

Primary mission is communication

Strong science component: Radio Science, Radio Astronomy, VLBI, Radar (GSSR)

Special task for DSS-25 (Goldstone 34-m beam-wave guide antenna) for advanced Radio Science experiments with Cassini at Ka-band.

Strong International collaboration in DSN Science



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Radio Science Experiments

Sensitivity limits

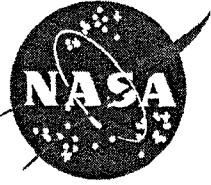
Frequency stability

Amplitude stability

Signal-to-noise ratio

Navigation accuracy

Intervening media



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Radio Science Instrumentation

Radio Science Receiver (open-loop)

**Tracking system (closed-loop):
Generates Doppler and Range**

Frequency and Timing Systems

All mechanical and electronic equipment that affect signal

- Antenna**
- Transmitter**
- Monitor System**

Advanced Media Calibration system

Remote Operations



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Basic Concepts of Data Types

One-way

Two-way

Open-loop

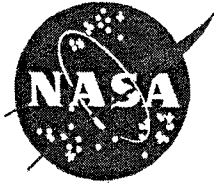
Closed Loop

Propagation

Gravitation

Data Processing

Archiving



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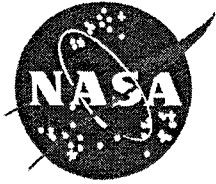


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Radio Science Instrumentation

Radio Science Receiver:

- Selectable recording bandwidth and sampling rates
- Designed with superior phase stability
- Signal Dynamics – frequency and amplitude variations
- Multi-path – any signal in recording bandwidth is captured
- Arraying and post-pass combining
- Creative post-processing



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Radio Science Instrumentation

Advanced Media Calibration system to calibrate Earth's atmosphere

Advanced Water Vapor Radiometer

Microwave Profiler

Meteorological Data

GPS Data



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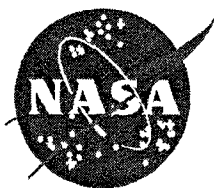
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Radio Science Instrumentation

Antenna Pointing

Accurate and often blind antenna pointing

- Aberration**
- Monopulse**



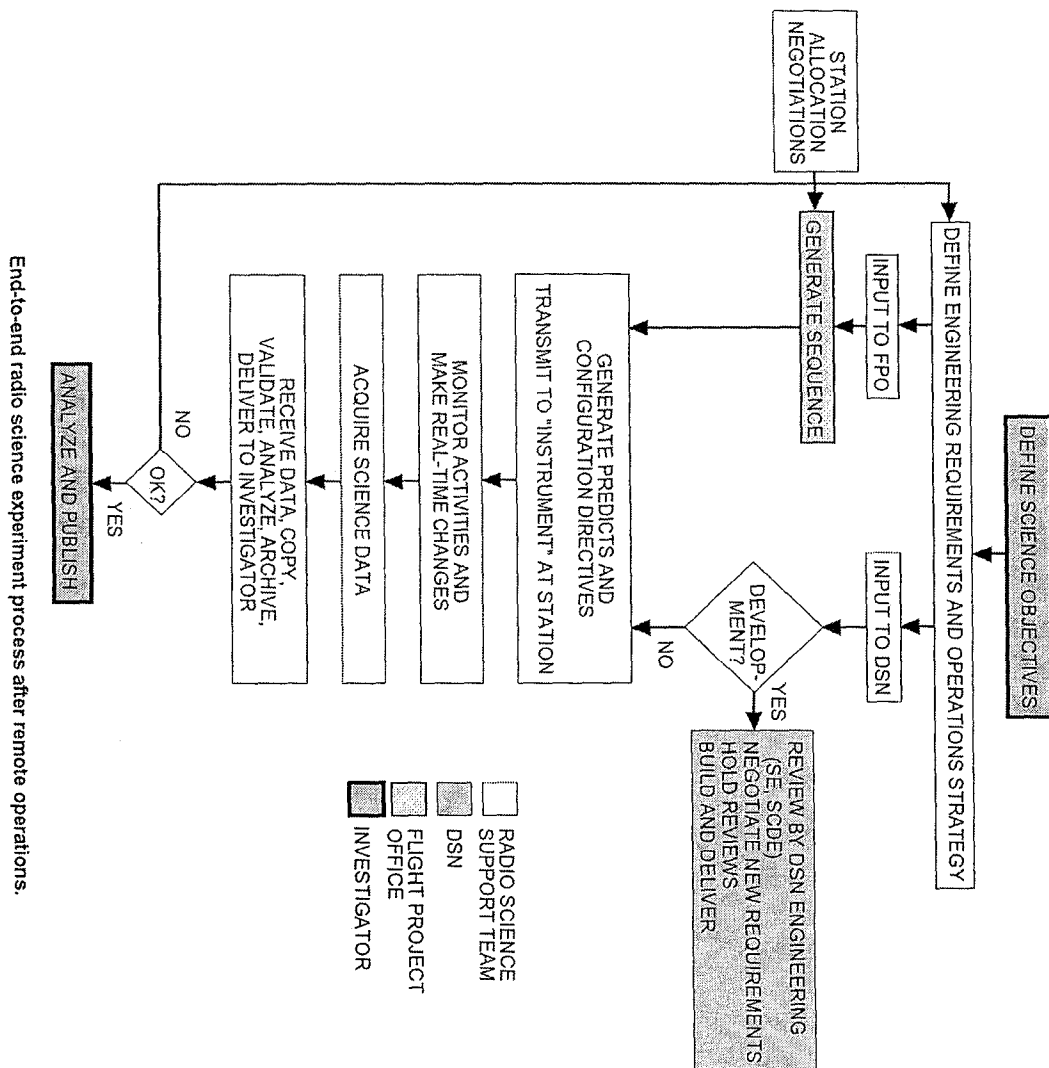
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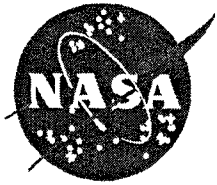


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Typical Experiment Operations

Station allocation

Spacecraft sequencing

Spacecraft configuration

- USO-reference, Telemetry modulation, Ranging

Station calibration and configuration

- Filter bandwidth and sampling rates
- Channel selection
- Doppler rate
- ranging parameters
- attenuation

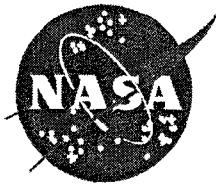
Predicts generation

Monitoring

Reacting to instrument problems

Data

- validation, logging, copying, distributing, archiving, processing, etc.



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How Complicated can a spacecraft radio get?

- **Ultra Stable Oscillators**
- **Transponders**
- **Translators**
- **Signal Processors**
- **Quiet well-pointed Spacecraft**

Receive uplink at both X- and Ka-bands

Transmit downlink at S-, X-, and Ka-bands

S1	X1	K1	referenced to the USO
S2	X2	K2	referenced to the X-band uplink
		K3	referenced to the Ka-band uplink

S-band system for the Huygens probe and Ku-band for radar